NREL/ORNL/DOE Distributed Power System Integration R&D

"Fast Response, Load-Matching Hybrid Fuel Cell"

Quarterly Review Meeting
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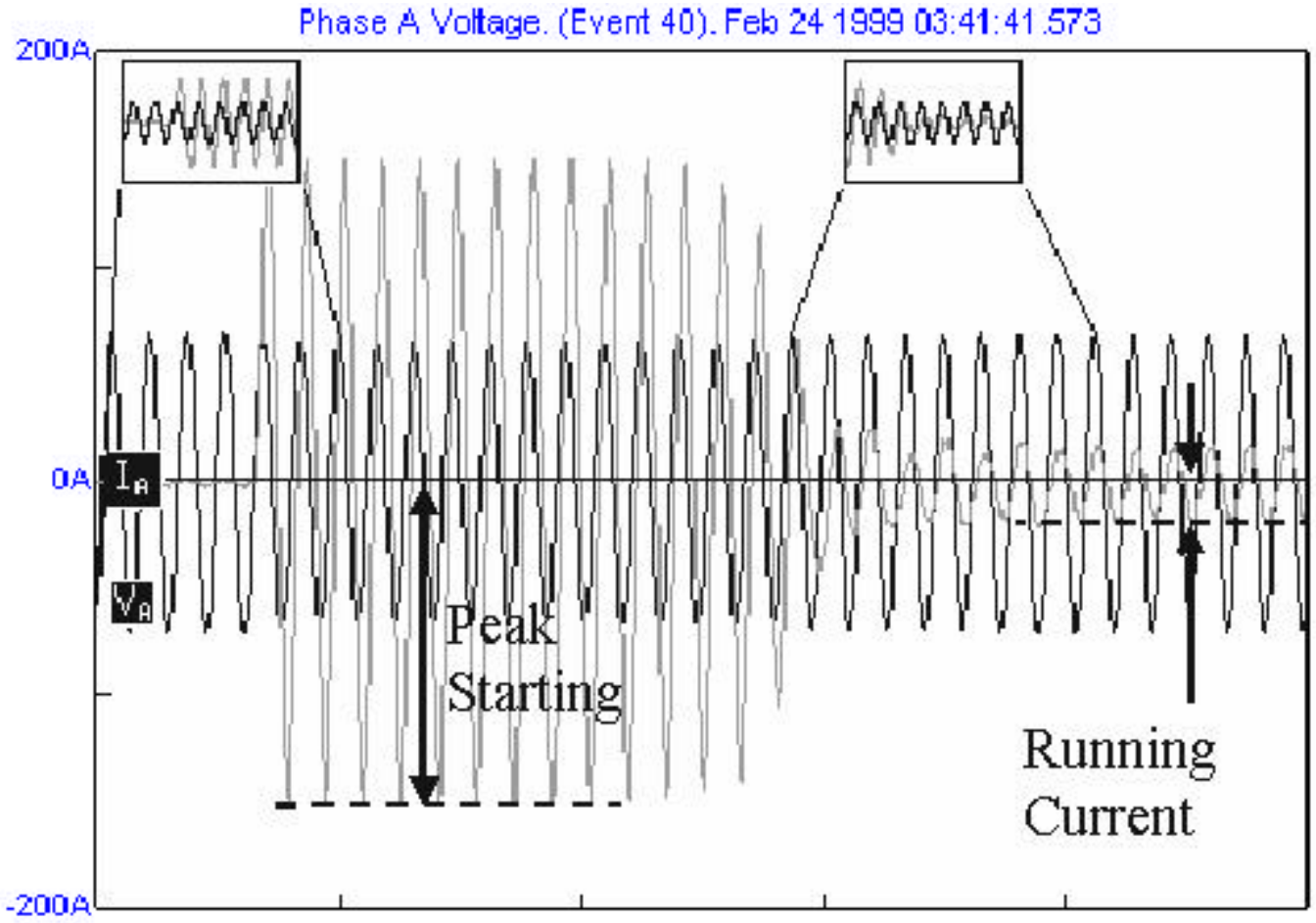
Project Overview

- **Objective** – Demonstrate the potential of hybrid DER technology with improved compatibility and performance characteristics.
- **Opportunity** – Most environmentally preferred advanced generators, e.g. PV, FC, Wind and ?-Turbines, do not provide the robust source characteristics expected in power system design.
- **3-Year Scope** – Design, assembly, system test and analysis of hybrid PEM fuel cell and high-power high-energy storage capacitors.

Project Benefits

- Pulse load capacity limits of typical DER (PEM fuel cell in this case) solved by hybrid application of ultra capacitors
- Hybrid can provide value added power conditioning for grid and load transients
- Application economics will be enhanced because a smaller fuel cell rating is capable of serving typical inrush and pulse loads

Additional Capacity Required for Starting Appliances



- ***Inrush Current and Effect on Service Voltage for Starting a Residential Heat Pump.***
- ***Monitoring shows peaks are 6-8 times average power draw.***

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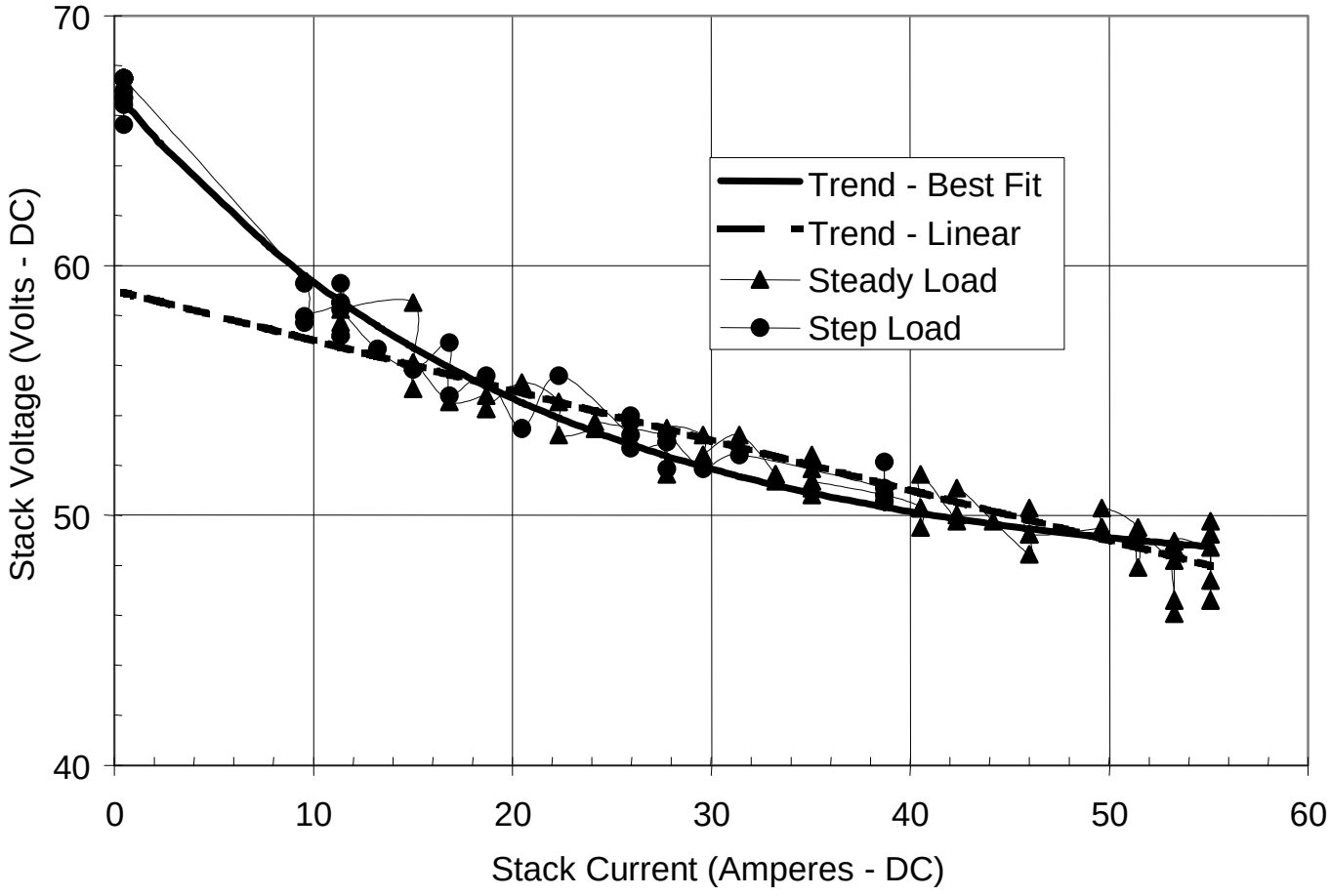
Current Status – End of Year 1 and Rap up

- Task 1 – Evaluate Individual Components, Cost and Performance
  - Evaluate 3-kW PEM Fuel Cell
  - Evaluate Electrochemical Capacitors
- Task 2 – Design a Fuel Cell/Electrochemical Capacitor Hybrid System
  - Provide specifications for ultracapacitor and fuel cell module into fuel cell
  - Address integration issues, step-load performance and capability as premium power supply
- Submitted first year report to NREL

Task 1: Fuel Cell Evaluation
3-kW PEM System Test Set Up

PEM Fuel Cell V-I Curve based on load tests



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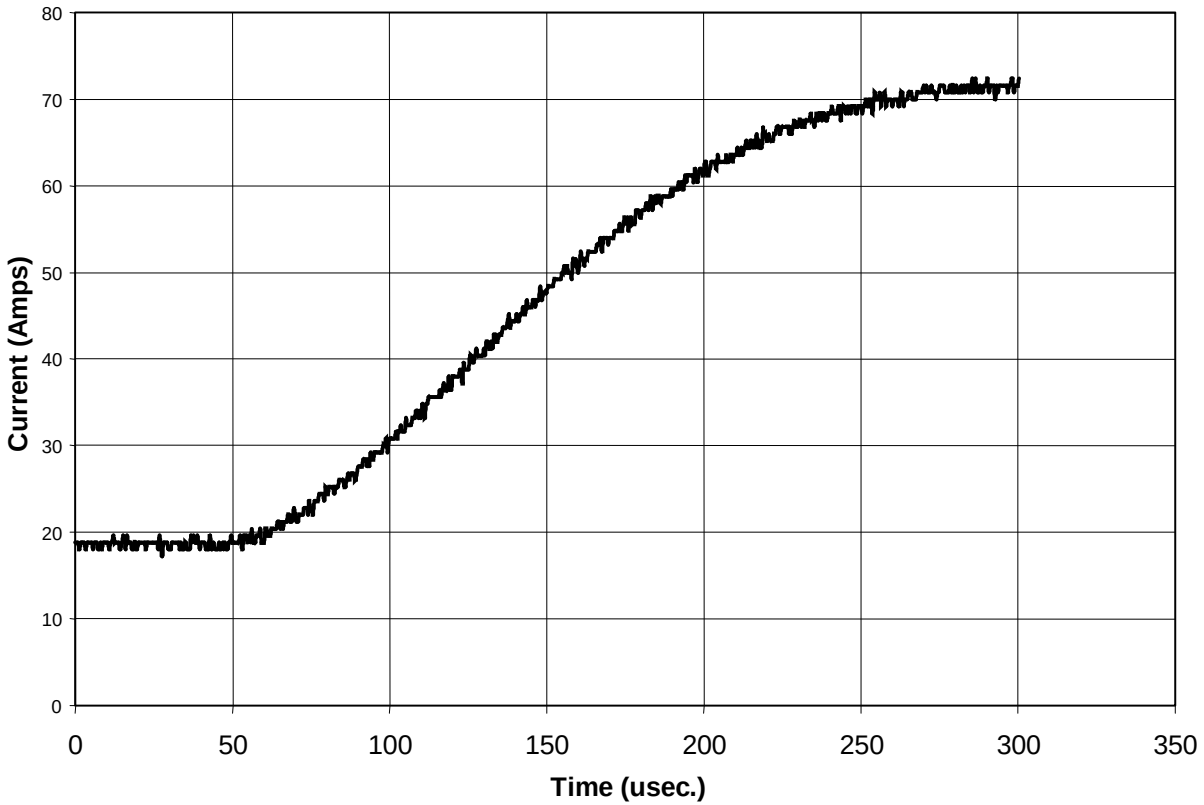
PEM Fuel Cell Step Load Response step load test



- 20-70 amps at 50 volts (1000-3500W) in less than 250 ?sec.

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Task 1: Ultracapacitor Selection and Evaluation

Parameter	Lead-Acid Batteries	DC Flywheels (1)	DC Ultra-Capacitors
Power @ 15s W/kg	20 – 330	10 – 130	120 – 1200
Energy @ 15s kJ/kg	10 – 6	10 – 6	10 – 6
Energy Range kJ/kg	93 – 6	10 – 2	12 – 2
Discharge Time Range	90 – .25 minutes	2 – 200 seconds	60 – 1 seconds
Recharge Time Range	Hours to Minutes	Minutes to Seconds	Minutes to Seconds
Roundtrip Efficiency (2)	70-80%	95-98%	97-99%
Typical Cycle Life	2,000 cycles	10,000 cycles	100,000 cycles
Cost $/kJ Range (3)	$.1 - 1	$1 – 4	$5 - 40
Technology Status	Mature	Available	Emerging

(1) Flywheel performance, cost, and weight includes generator and containment

(2) Assumes a slow recharge for best-case efficiency

(3) First cost over rated discharge time range from longest (lowest cost) to shortest time (highest cost)

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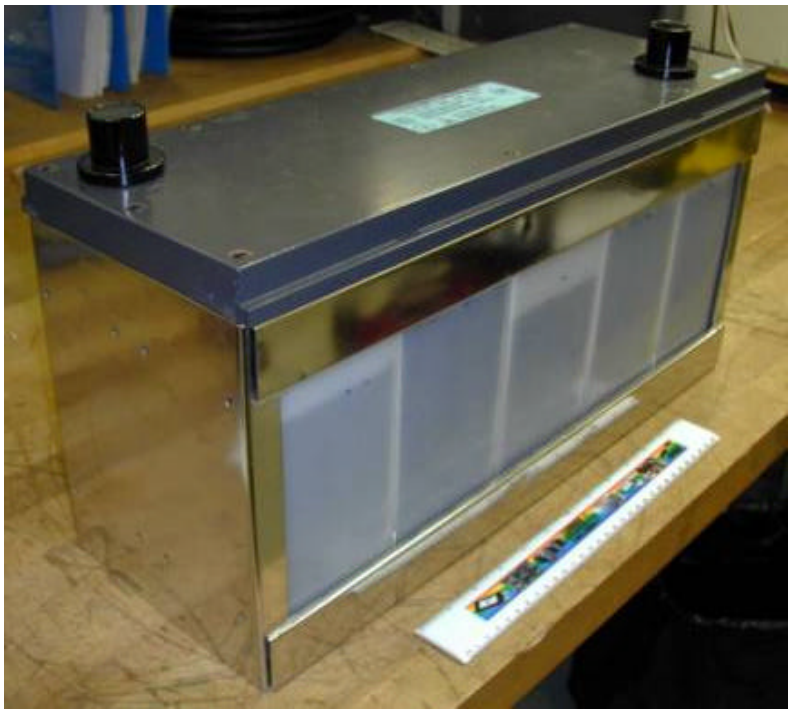
16-V double-layer electro-chemical ultra capacitors

- Higher-power, efficiency, and cycle life, faster recharging compared to lead-acid batteries more modular than flywheels.
- 20% - 30% of the energy in a typical auto battery



ESMA 8-16Vdc, 1 MJ, 34 kg

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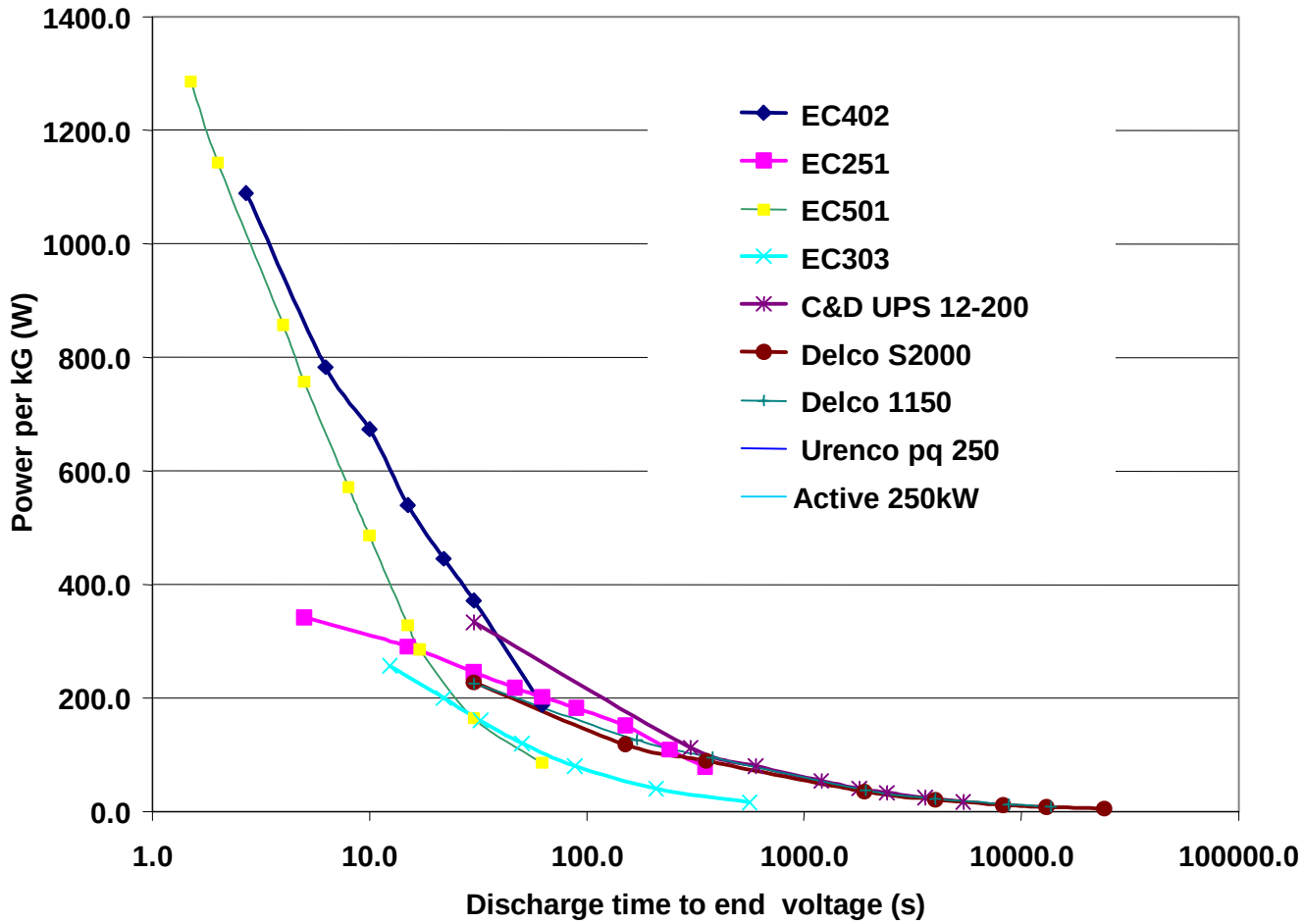
Comparison of Watts per kG for different discharge times



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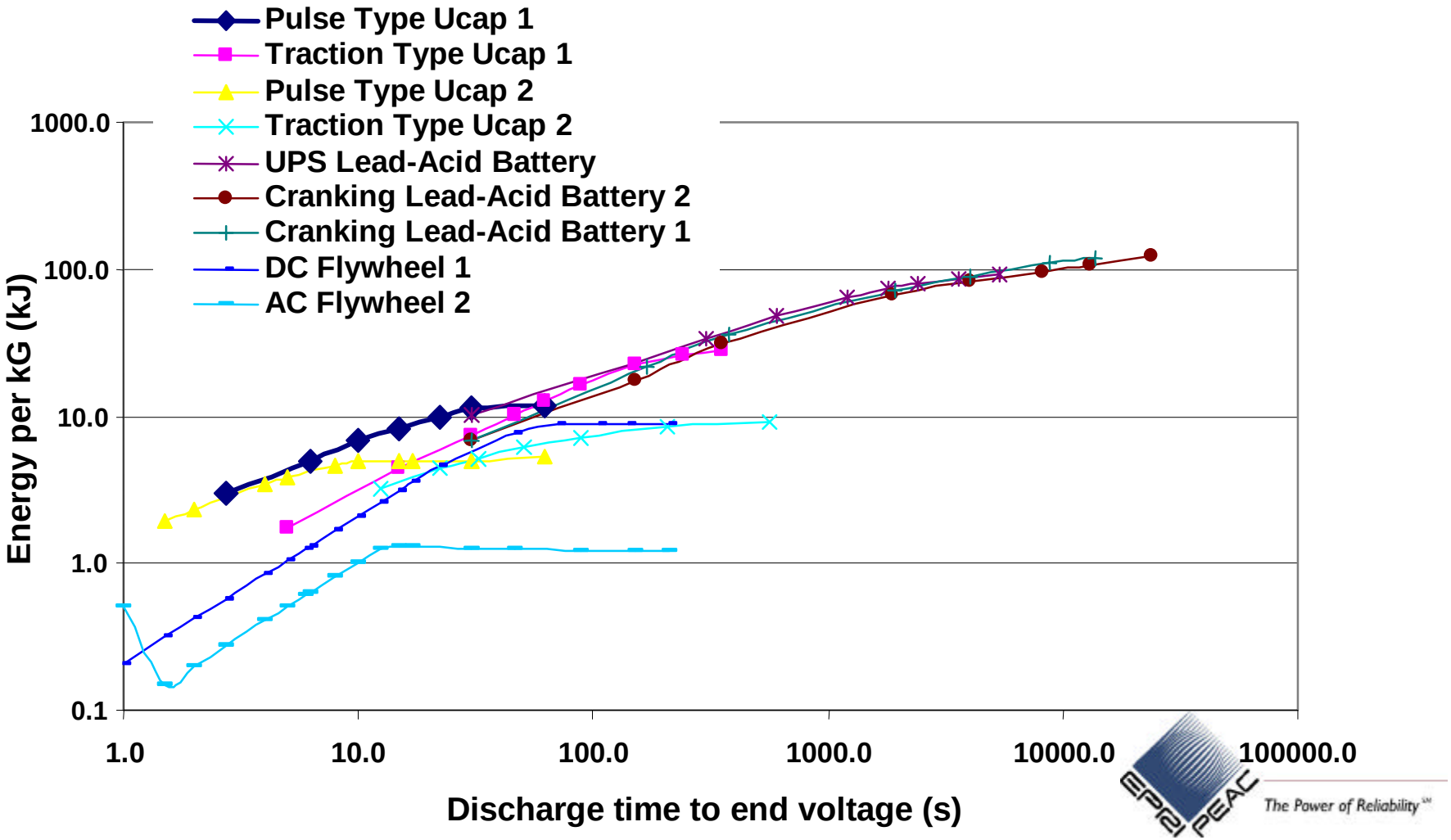

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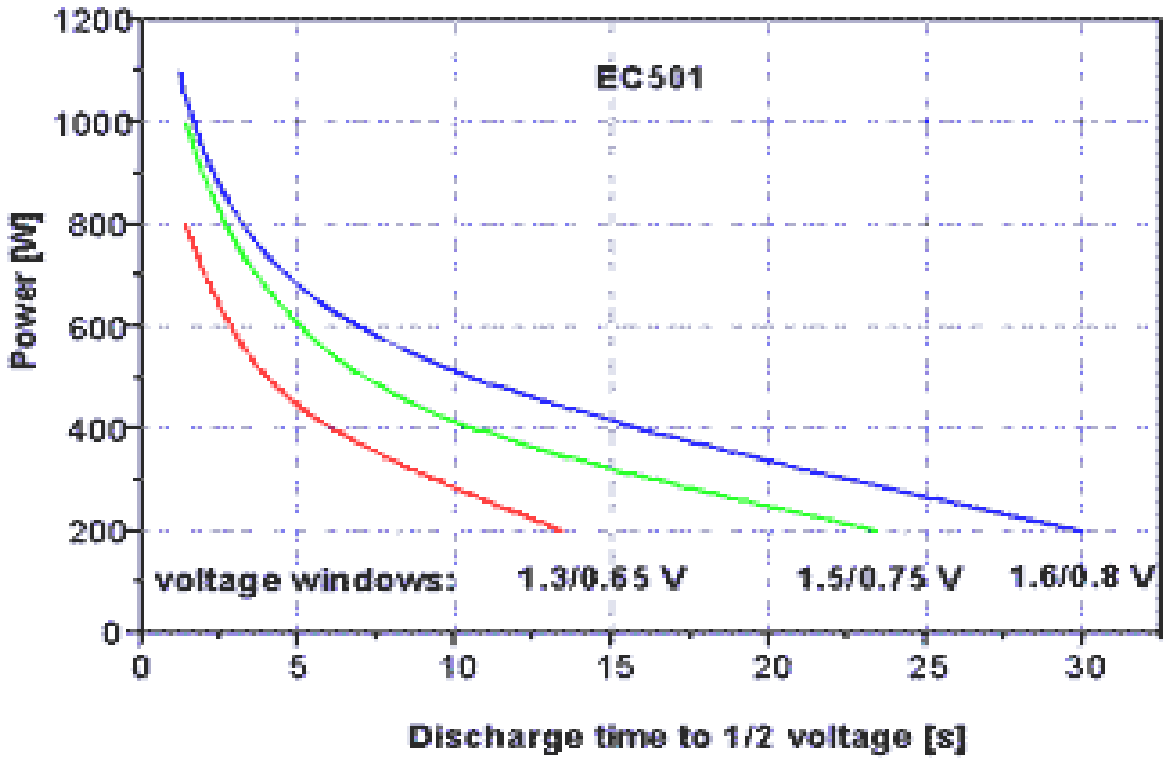
Selected Ultra Capacitor Module

Capacitor module type	Rated operating voltage window, V	Capacitance F, not less than	Energy stored in rated operating voltage window, kJ, not less than	Internal resistance at +20 °C (-30 °C), mOhm, not more than
10EC501.2-35-13/6.5-0.0035	13 - 6.5	600	35	3.5(4.5)



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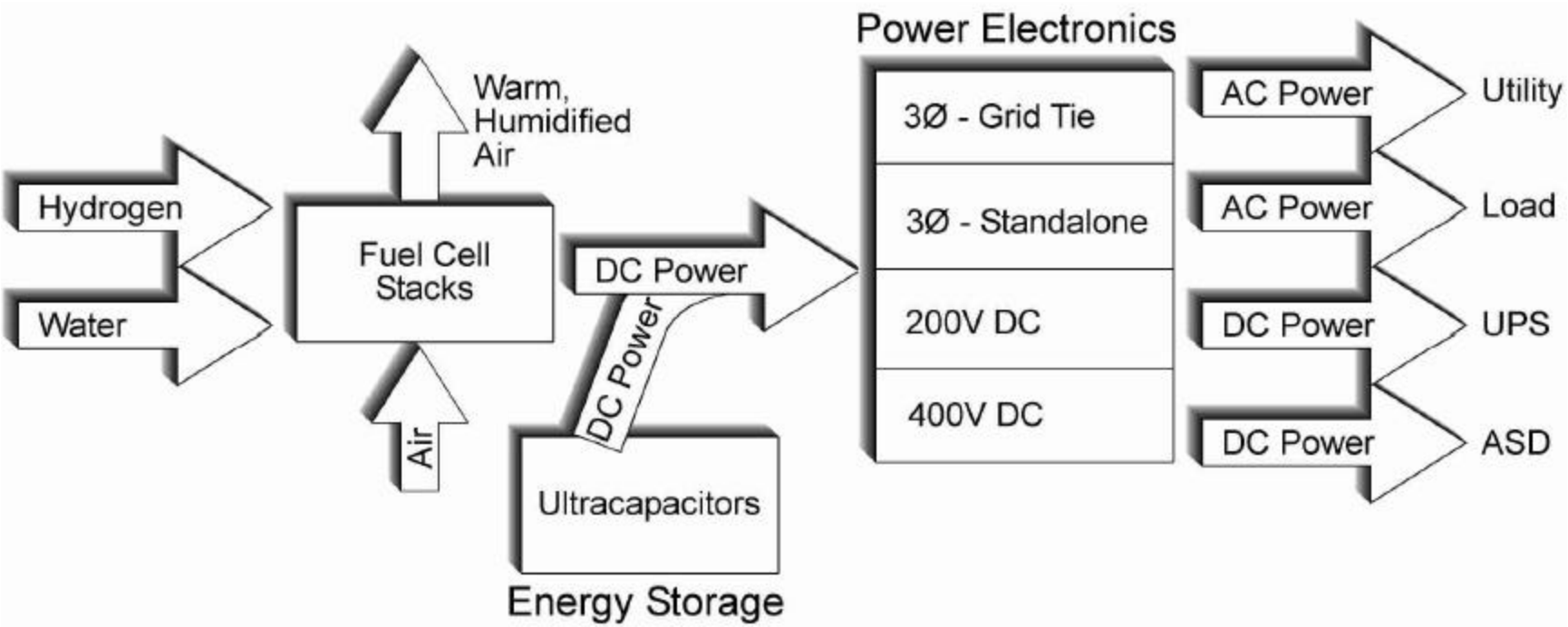
Task 2: Hybrid System Design Configuration and Test Results



- Fuel cell system designed for robust grid connection and response with potential improve load and grid support via ultra capacitors

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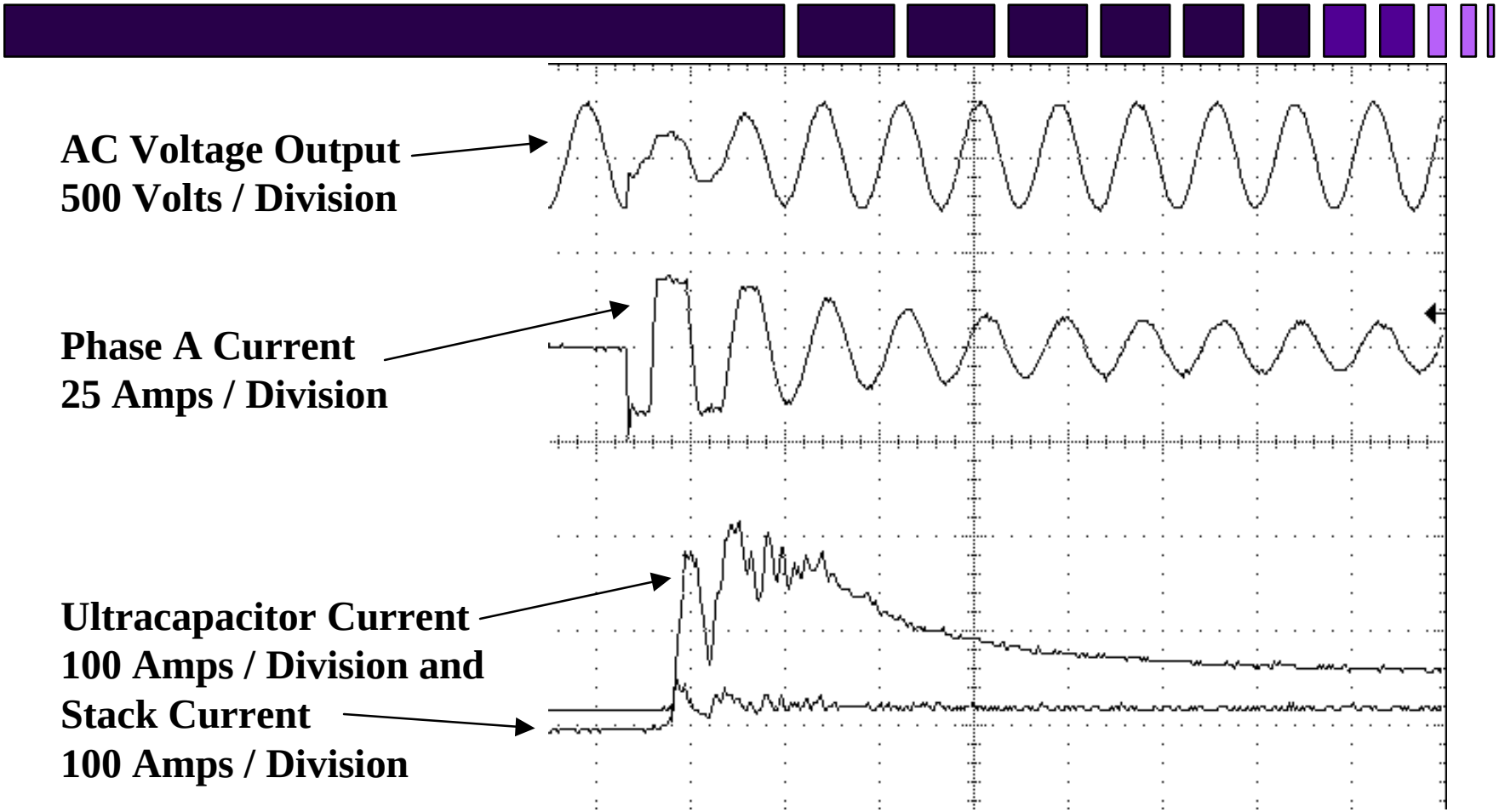
3-kW PEM Fuel Cell and U-cap Hybrid System

- **4-14Vdc Ultra Capacitors, 56Vdc in base of fuel cell cabinet**
- **40 cells at 4.41 kJ/cell ~ 176 kJ**
- **Cost is ~ $50/cell, $2000 total**

Start from 0 to 100% Loading



Step Loading to Full Load When Ultracapacitor is Charging. Timebase is 20 Msec per Division

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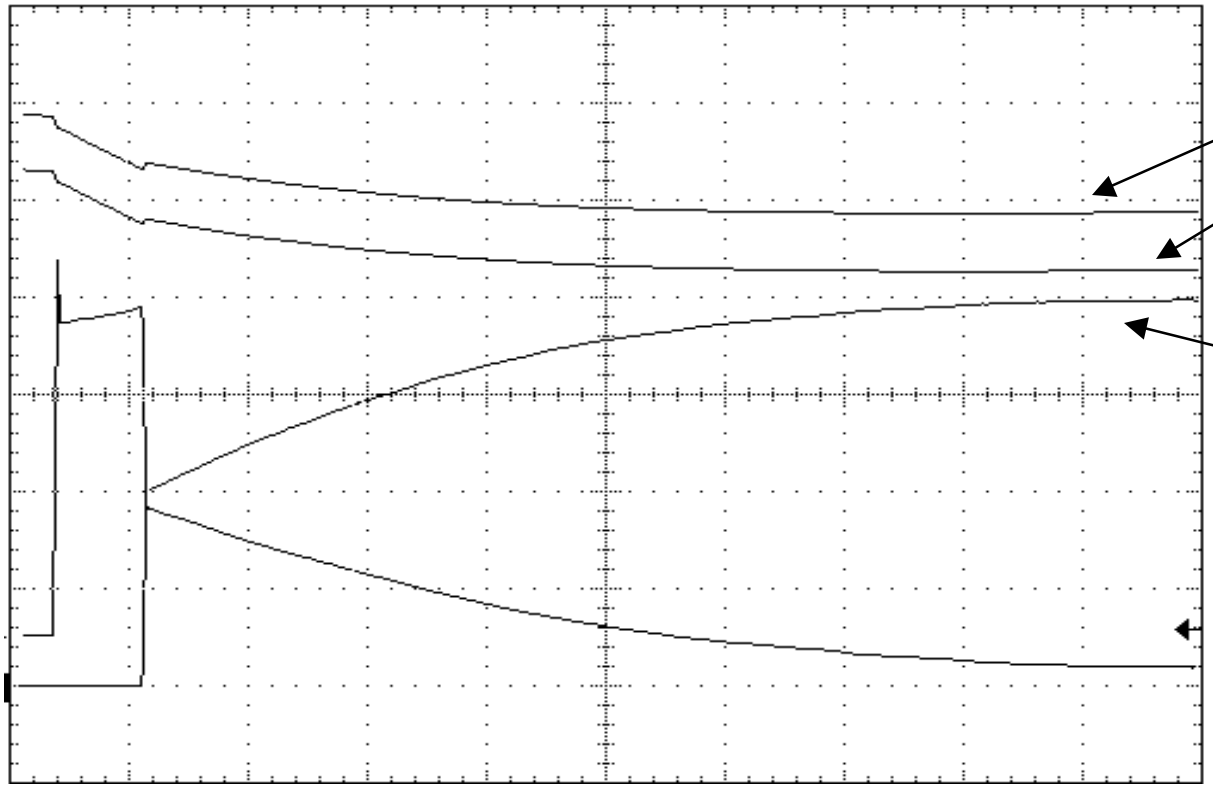
System Step Response – 1.5 HP Motor Start



Stack voltage and
UCap voltages 10 Volts / Div

Stack Current 20 Amps / Division

Ultracapacitor Current 20 Amps / Division

Startup of a 1 ½ HP Motor, Three-Phase, 208 V (Timebase is 10 Seconds/Division)

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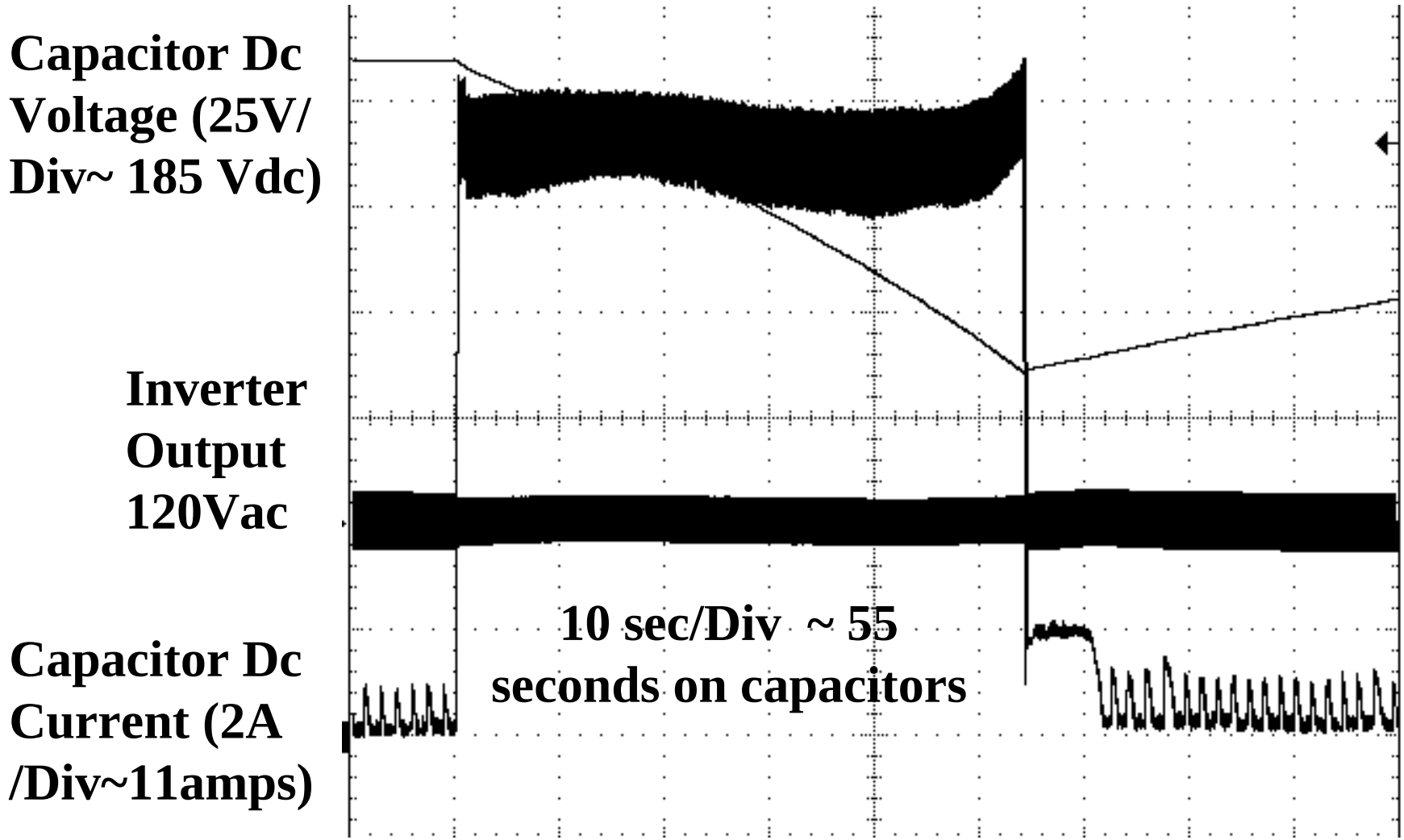
Momentary Loss of Fuel Cell Stack Voltage



Note: No measurable change after 2000 ride-thru cycles

Conclusion: Year 1 Report Contains

1. Introduction
   - Improving Dynamic Performance of DER Hybrid Technologies
   - Scope Of Work
2. Component and System Test Results
   - PEM Fuel Cell, Asymmetrical Ultracapacitor, Hybrid System
3. Hybrid System Design and Specification
   - Design of Fuel Cell, Storage, Hybrid System Design and Cost
4. Related Grid-Interconnection Practices
   - Power conversion, relays, interconnection transformer, etc.
5. Recommendations for Related Work
   - Other "hybrid" DER systems, intelligent interface
6. Related Reading

Appendix on Double-Layer Electro-Chemical Capacitors